QUARTZ CRYSTAL

MICROBALANCE - OPERATION

Operation

Resonator Crystals

When the QCM was first developed, natural quartz was harvested, selected for its quality and then cut in the lab. However, most of today's crystals are grown in the lab using seed crystals. The seed crystals serve as an anchoring point for crystal growth; encouraging growth in two directions and limiting growth in another. The crystals, AT or SC (discussed below) used in most applications operate in the thickness shear mode at a frequency in the 1-30 MHz range.

Electromechanical Coupling

The QCM consists of a thin piezoelectric plate with electrodes evaporated onto both sides. Due to the piezo-effect, an AC voltage across the electrodes induces a shear deformation and vice versa. The electromechanical coupling provides a simple way to detect an acoustic resonance by electrical means.

Otherwise, it is of minor importance. However, electromechanical coupling can have a slight influence on the resonance frequency via piezoelectric stiffening. This effect can be used for sensing, but is usually avoided. It is essential to have the electric and dielectric boundary conditions well under control. Grounding the front electrode (the electrode in contact with the sample) is one option. A π-network sometimes is employed for the same reason. A π-network is an arrangement of resistors, which almost short-circuit the two electrodes. This makes the device less susceptible to electrical perturbations.

Shear Waves Decay in Liquids and Gases

Most acoustic-wave-based sensors employ shear (transverse) waves. Shear waves decay rapidly in liquid and gaseous environments. Compressional (longitudinal) waves would be radiated into the bulk and potentially be reflected back to the crystal from the opposing cell wall. Such reflections are avoided with transverse waves. The range of penetration of a 5 MHz-shear wave in water is 250 nm. This finite penetration depth renders the QCM surface-specific. Also, liquids and gases have a rather small shear-acoustic impedance and therefore only weakly damp the oscillation. The exceptionally high Q-factors of acoustic resonators are linked to their weak coupling to the environment.

Modes of Operation

Economic ways of driving a QCM make use of oscillator circuits. Oscillator circuits are also widely employed in time and frequency control applications, where the oscillator serves as a clock. Other modes of operation are impedance analysis and ring-down. In impedance analysis, the electric conductance as a function of driving frequency is determined by means of a network analyzer. By fitting a resonance curve to the conductance curve, one obtains the frequency and bandwidth of the resonance as fit parameters. In ring-down, one measures the voltage between the electrodes after the exciting voltage has suddenly been turned off. The resonator emits a decaying sine wave, where the resonance parameters are extracted from the period of oscillation and the decay rate.

Energy Trapping

The electrodes at the front and the back of the crystal usually are key-hole shaped, thereby making the resonator thicker in the center than at the rim. This confines the displacement field to the center of the crystal by a mechanism called energy trapping. The crystal turns into an acoustic lens and the wave is focused to the center of the crystal. Energy trapping is necessary in order to be able to mount the crystal at the edge without excessive damping.

Energy trapping slightly distorts the otherwise planar wave fronts. The deviation from the plane thickness-shear mode entails flexural contribution to the displacement pattern. Flexural waves emit compressional waves into the adjacent medium, which is a problem when operating the crystal in a liquid environment.

Overtones

Planar resonators can be operated at a number of overtones, typically indexed by the number of nodal planes parallel to the crystal surfaces. Only odd harmonics can be excited electrically because only these induce charges of opposite sign at the two crystal surfaces. Overtones are to be distinguished from anharmonic side bands (spurious modes), which have nodal planes perpendicular to the plane of the resonator. The best agreement between theory and experiment is reached with planar, optically polished crystals for overtone orders between n = 5 and n = 13. On low harmonics, energy trapping is insufficient, while on high harmonics, anharmonic side bands interfere with the main resonance.

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